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DETECTION OF PREAMBLE OF INBOUND
SIGNAL IN RDSS SYSTEM

by

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ABSTRACT A theoretical analysis is carried out with regard to RDSS inbound signal fast acquisition systems, deriving optimum detection systems for preambles as well as approximately optimum detection systems for preambles. At the same time, analysis is carried out with regard to the performance of approximately optimum detection systems. Test measurements clearly show that theoretical analysis and experimental results are in line with each other.

SUBJECT TERMS RDSS Signal detection Performance analysis

1 SUMMARY

Dual satellite positioning systems (RDSS) are one type of new model navigation positioning system. They are composed of two satellites, ground central stations, and user equipment. Their biggest special characteristic is the small number of satellites that compose the system. User equipment is simple. All complexities are concentrated in the ground central station.

Dual satellite positioning system signals entering into central stations are called inbound signals. Their characteristics are:

(1) Direct sequence expansion frequency signals. Expansion frequency code speed is 8Mbit/s;

(2) Short bursts (20-80 ms). That is nothing else than user reply signals being random. Central stations certainly do not know beforehand the time of user reply signals;

(3) Multiplex nature--the system is a multiple user system. As far as a certain number of user replies are concerned, their entry into central stations is random, and it is possible for them to overlap each other;

(4) Low signal to noise ratios--there is a requirement for incoming signal to noise ratios to be -20~-22dB.

Dual satellite positioning systems demand that central stations acquire pseudo codes associated with inbound signals within 1 ms time periods. Opting for the use of conventional acquisition methods, it is not possible to realize the acquisition of pseudo codes. The method for which option is made here is the insertion of synchronicity guidance sequences (that is, synchronicity preambles) into inbound signals. Entire inbound signals are composed of synchronicity guidance sections (preambles), tracking sections, and data sections. When central stations receive inbound signals with this type of format, it is, first of all, necessary to carry out acquisition of synchronicity preambles. At the instants when preamble codes finish, a synchronicity pulse is produced to make delay lock in loops roughly synchronous. In this way, the problem of fast acquisition of inbound signals then turns into a detection problem with regard to synchronicity preamble pseudo codes. Synchronicity preamble formats are as shown in Fig.1.

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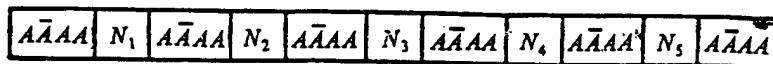


Fig.1 Synchronicity Preamble Sequence Format Note: A is 255 digit random pseudo code. \overline{A} is the inverse code of A; $N_1 - N_5$ are intervals.

From the analysis above, it is possible to see that dual satellite positioning fast acquisition techniques are a key

technology in dual satellite positioning systems. They are also a difficulty. If synchronicity preambles are not picked up, this type of dual satellite positioning system cannot then be set up. This article is nothing else than the carrying out of a theoretical analysis with regard to fast acquisition systems starting out from statistical detection theory.

2 MATHEMATICAL MODELS ASSOCIATED WITH SIGNAL DETECTION AND OPTIMUM DETECTION SYSTEMS

During transmission processes, signals $s(t)$ cannot avoid being subject to interference associated with noise $n(t)$. As a result, signals received by detection systems only have two types of possibilities:

- (1) Signal plus noise $x(t) = s(t) + n(t)$
- (2) Pure noise $x(t) = n(t)$

The task of detection systems is to carry out processing or operations on sampling value sequences associated with inputted wave forms $x(t)$, that is, samples $(x_1, x_2, x_3, \dots, x_n)$. After that, on the basis of the output, there is a determination whether or not a signal exists. In dual satellite positioning systems, during applications, processing is only carried out with respect to synchronous preamble signals. After that, on the basis of detection system output, at the instants pseudo codes begin to be set up, tracking is started up with regard to long codes. This is nothing else than the detection problem associated with synchronous preambles in dual satellite positioning systems.

In dual satellite positioning systems, user reply signals are bursts and are also random. As a result, during synchronous detection determinations of synchronous preamble signals, the criterion option is made for the use of is the Naiman-Piersun (phonetic) criterion. The requirement associated with this criterion is--under conditions which permit a certain probability of false alarm p_{ra} --to make leak alarm probability p_l reach a minimum and to make the probability of correct detection p_d reach a maximum, that is

$$\begin{aligned} p_{ra} &= a = \text{constant} \\ p_d &= 1 - p_l \quad \text{maximum} \end{aligned}$$

On the basis of Naiman-Piersun (phonetic) criteria, the derived optimum detection system is a likelihood ratio computer and a threshold determination device (as in Fig.2). $\Lambda(x)$ is the likelihood ratio. Threshold value Λ_0 is determined on the basis of p_{ra} values.

The determination standards are

$$\begin{aligned} \Lambda(x) &\geq \Lambda_0 && \text{determination of signal present} \\ \Lambda(x) &< \Lambda_0 && \text{determination of no signal} \end{aligned}$$

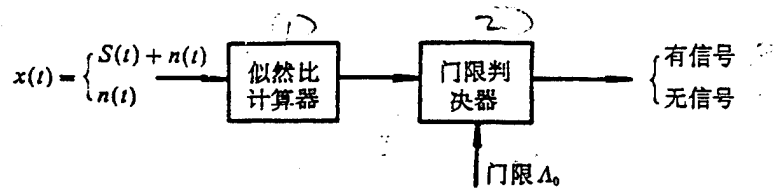


Fig.2 Optimum Signal Detection System

Key: (1) Likelihood Ratio Computer (2) Threshold Determination Device (3) Signal Present (4) No Signal (5) Threshold /42

3 OPTIMUM DETECTION OF SYNCHRONOUS PREAMBLE SIGNALS

Signals entering detection systems are (signals and noise both limited to within the $(-f_c, +f_c)$ frequency band)

$$x(t) = \begin{cases} s(t) + n(t) & \text{signal exists} \\ n(t) & \text{no signal} \end{cases}$$

$s(t)$ is synchronous preamble pseudo code signal

$$s(t) = \sqrt{2s} p(t) \cos(\omega_0 t + \omega_d t + \phi_s)$$

In equations, ω_0 is the central frequency. ω_d is Doppler frequency shift. s is signal power. ϕ_s is random phase. $p(t)$ is synchronous pseudo code basic band signal.

Assume that the mean value of $n(t)$ is zero, variance is $\sigma^2 = f_c N_0$ band limit stable Gaussian random noise, and N_0 is mean noise power.

Here, for the sake of making discussion convenient, make $\omega_d = 0$ and $2s = 1$. One then has

$$s(t) = p(t) \cos(\omega_0 t + \phi_s)$$

Taking $s(t)$, the expansion is

$$s(t) = sI(t) \cos \phi_s - sQ(t) \sin \phi_s$$

In equations $sI(t) = p(t) \cos \omega_0 t$; $sQ(t) = p(t) \sin \omega_0 t$.

Optimum detection systems must first of all calculate likelihood ratios. Due to signals possessing unknown quantities ϕ_s , calculations of the mean likelihood ratios are, therefore,

$$\bar{\Lambda}(x) = \int_{\varphi_1} \Lambda(x/\varphi) p(\varphi) d\varphi \quad (1)$$

Moreover, condition likelihood ratios $\Lambda(x/\varphi)$ is [1]

$$\Lambda(x/\varphi) = \exp \left[-\frac{E_s(\varphi)}{N_0} + \frac{2}{N_0} \int_0^T x(t) s(t, \varphi) dt \right] \quad (2)$$

In equations, $E_s(\varphi) = \int_0^T p^2(t) \cos^2(\omega_0 t + \varphi) dt \approx \frac{1}{2} \int_0^T p^2(t) dt = E$

E is signal energy. T is the last s(t) moment.
With regard to the integral second term

$$\frac{2}{N_0} \int_0^T x(t) s(t, \varphi) dt = \frac{2}{N_0} \int_0^T s_I(t) x(t) \cos \varphi dt - \frac{2}{N_0} \int_0^T s_Q(t) x(t) \sin \varphi dt$$

let $y_I = \int_0^T s_I(t) x(t) dt$ $y_Q = \int_0^T s_Q(t) x(t) dt$

Introducing $r = \sqrt{y_I^2 + y_Q^2}$ $a = \arctg(y_Q/y_I)$

then, correlation integration term

$$\frac{2}{N_0} \int_0^T x(t) s(t, \varphi) dt = \frac{2}{N_0} r \cos(\varphi + a) \quad (3)$$

From equations (1), (2), and (3), one obtains

$$\bar{\Lambda} = \frac{1}{2\pi} \exp(-E/N_0) \int_0^{2\pi} \exp \left[\frac{2}{N_0} r \cos(\varphi + a) \right] d\varphi = \exp(-E/N_0) I_0(2r/N_0)$$

$$I_0(u) = \frac{1}{2\pi} \int_0^{2\pi} \exp[ucos(\varphi + a)] d\varphi \quad \text{is the type 1 zero order Bessel function.} \quad /43$$

$p(\varphi)$ is the probability distribution function associated with φ s. It is a uniform distribution from 0 - 2π .

In accordance with the composition of optimum signal detection systems, the synchronicity preamble signal detection rule is

$$\bar{\Lambda}(x) = \exp(-E/N_0) I_0(2r/N_0) \geq \Lambda_0 \quad \text{signal presence determined.}$$

This is also nothing else than $I_0(2r/N_0) \geq \Lambda_0 \exp(E/N_0)$

determined as there being signal present.

The equations above explain optimum detection systems first of all calculating out $I_0(2r/N_0)$. However, zero order calibration Bessel functions are monotonic functions of r . In this way, detection systems then simplify to be calculation devices for computing r . Afterwards, a threshold determination device is added. The line and block composition of synchronicity preamble signal optimal detection systems associated with the calculation of r values is as shown in Fig.3.

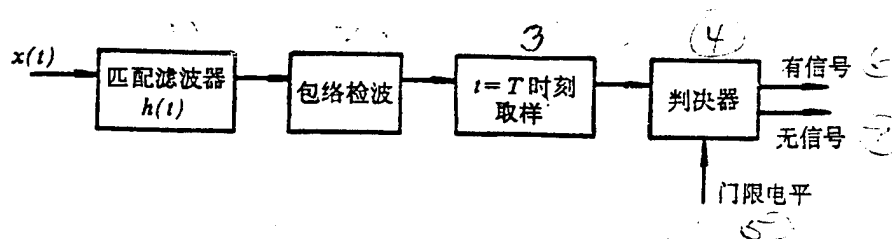


Fig.3 Synchronicity Preamble Signal Optimal Detection System

Key: (1) Matching Wave Filter Device (2) Envelope Detection
(3) $t = T$ Instant Sampling (4) Determination Device (5)
Threshold Electric Level (6) Signal Present (7) No Signal

4 APPROXIMATELY OPTIMUM SYNCHRONICITY PREAMBLE SIGNAL DETECTION SYSTEMS

From Fig.3, it is possible to see that, in terms of theory, synchronicity preamble signal optimum detection systems derived are constructed from matching wave filter devices, detectors, maximum value selection systems, and determination devices. In reality, optimum detection systems are very difficult to realize. It is only possible to opt for the use of approximately optimum detection systems to actualize detection with respect to signals.

In reality, signals are synchronous preambles associated with going through BPSK modulation. Its matching wave filter devices are as shown in Fig.4. In actuality, A sequence medium frequency matching wave filter devices are very difficult to realize, and their actualization is only approximately possible. In developing successful fast acquisition systems, A sequence matching wave filter devices opt for the use of surface acoustic wave instruments for approximate realization.

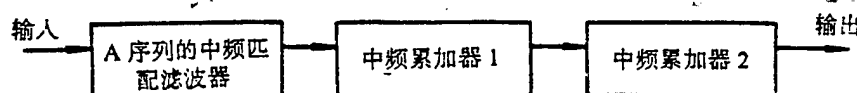


Fig.4 Synchronicity Preamble Signal Medium Frequency Matching Wave Filtration

Key: (1) Input (2) A Sequence Medium Frequency Matching Wave Filter Device (3) Medium Frequency Summation Device 1 (4) Medium Frequency Summation Device 2 (5) Output

On the other hand, in reality, due to the existence of Doppler frequencies, they have influences, in all cases, with regard to main correlation peaks and matching wave filter device outputs. As a result, medium frequency summation device 2 is certainly not capable of accumulating in medium frequencies but is accumulating in visual frequencies. That is also nothing else than taking the output of medium frequency summation device 1 to carry out detection. After that, a second accumulation is carried out. In this way, an approximate matching wave filter device is then constructed with regard to synchronous preamble signals.

In dual satellite positioning systems, opting for the use of simple, fixed time gate tolerance determination circuits is already not able to satisfy requirements. For this reason, a specialized determination system was designed (as shown in Fig.5)[1]. What it opts for the use of are gate tolerance delayed determination methods. There are two points associated with the theoretical foundation. (1) Based on determination devices associated with optimum detection systems, output after visual frequency accumulation is compared with gate tolerance electric levels, constructing the first condition associated with determination devices. Determinations are carried out on the entire time axis--for example the dotted line box I in Fig.5. (2) On the basis of the principles of binary accumulators, the second condition associated with determination systems is designed--for example, dotted line box II in Fig.5. This circuit is nothing else than a binary accumulator designed on the basis of binary accumulator principles. Option is made for the use of parallel methods. During determinations--before visual frequency accumulation--6 circuit signals are inputted at the same time into gate comparators. Only so long as there are open gate electric levels do the 6 circuit gate comparators then simultaneously input signals, comparing with gate tolerance 3 and then doing

summations. Finally, comparisons are made with gate tolerance 2. (1) and (2) are two foundations that the design of determination systems cannot do without.

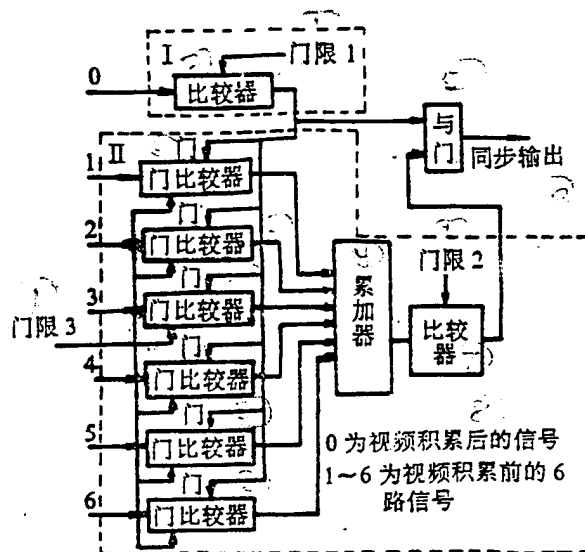


Fig.5 Schematic Diagram of Synchronicity Preamble Signal Determination System

Key: (1) Gate Tolerance (2) Comparator (3) Gate Gate Comparator (4) Summation Device (5) Comparison Gate (6) Synchronous Output (7) Comparator (8) 0 is the signal after video frequency accumulation. 1-6 are 6 channel signals before video accumulation.

In actuality, the entire synchronous preamble signal approximately optimum detection system is also nothing else than the development of a successful fast acquisition system (as shown in Fig.6).

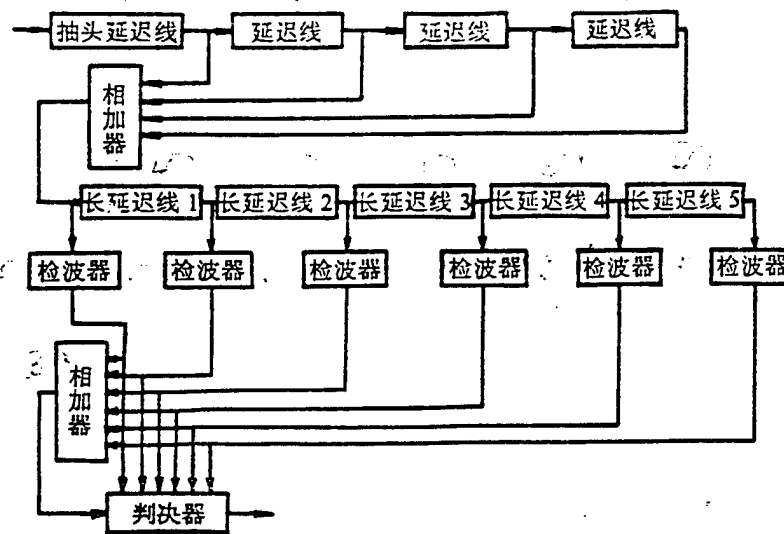


Fig.6 Synchronous Preamble Signal Approximately Optimum Detection System

Key: (1) Plug Delay Line (2) Delay Line (3) Adder (4) Long Delay Line (5) Detector (6) Determination Device

5 FAST ACQUISITION SYSTEM DETECTION CAPABILITIES

In accordance with Naiman-Piersun (phonetic) criteria, use is made of false alarm probability p_{fa} and acquisition probability p_d in order to express detection system detection capabilities. For this reason, it is necessary to solve probability density functions when there is only noise and probability density functions when there is signal plus noise./45 Signal plus noise probability functions are divided into two types. One type is main correlation peak probability density functions and side lobe plus noise probability density functions.

Probability density functions associated with envelope r when there is no signal present--after medium frequency accumulation detection--are

$$p(r/0) = \text{rexp}(-r^2/2) \quad r \geq 0$$

The distribution associated with the equation above is a Rayleigh distribution. The explanation of this is that probability density functions r , when there is only noise present, are also Rayleigh distributions. Probability density functions when there are signals present are

$$p(r/s) = \text{rexp}\left[-\frac{1}{2}\left(r^2 + \frac{2E}{N_0}\right)\right] I_0\left(r \sqrt{2E/N_0}\right)$$

This equation is a generalized Rayleigh distribution. It is also called a Rice distribution. In the equation, $2E/N_0$ is an instantaneous power signal to noise ratio. Probability density functions associated with signals after video frequency accumulation are

when there are signals

$$p(y/s) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(y - \bar{y})^2}{2\sigma^2}\right)$$

In this, the mean value

$$\bar{y} = N + E_1/N_0$$

E_1/N_0 is the instantaneous signal to noise ratio after video frequency accumulation. $E_1 = N \times E$ is signal energy after video frequency accumulation.

variance

$$\sigma^2 = \bar{y}^2 - \bar{y}^2 = N + 2E_1/N_0$$

when there is no signal

$$p(y/0) = \frac{1}{\sqrt{2\pi N}} \exp\left(-\frac{(y - N)^2}{2N}\right)$$

The mean value $\bar{y} = N$; variance $\sigma^2 = N$; N is an integer associated with random variables. Here, $N = 6$.

In fast acquisition systems, option is made for the use of gate tolerance delayed determination methods. In this way, before main peaks have appeared, side lobes will then appear. After side lobes go over gate tolerances, erroneous signal detection is then created, producing mistaken synchronicity command signals. There is, therefore, a need to make signals capable of being detected at peak value instants. It is then necessary to avoid detecting side lobes. Giving considerations to the influences of side lobes, overall detection probability can be expressed as [3]

$$p_d = p_{dm} \prod_{k=1}^{n-1} (1 - p_{dsk}) \quad (4)$$

In equations, p_{dm} is main peak detection probability. p_{dsk} is the probability of detecting side lobes with a range of k .

The largest side lobes have the greatest influence on detection probabilities. Here, the largest side lobes are 1/6 of main peak values. As a result, equation (4) can be rewritten to be

$$p_d = p_{dm} (1 - p_{as}) = p_{dm1} \times p_{dm2} (1 - p_{as1} \times p_{as2})$$

pdml and pdm2 are, respectively, the main peak detection probabilities associated with determination system no.1 channel and no.2 channel;
pas1 and pas2 are, respectively, the side lobe detection probabilities associated with determination system no.1 channel and no.2 channel.

In this
$$p_{dm1} = \int_{v_T}^{+\infty} p(y/s) dy = \int_{v_T}^{+\infty} \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(y - \bar{y})^2}{2\sigma^2}\right] dy$$

In equations, $\sigma^2 = N + 2E_{lm}/N_0$; $\bar{y} = N + E_{lm}/N_0$; E_{lm}/N_0 is the signal to noise ratio associated with main peak values.

V_T is gate tolerance. V_T can be determined on the basis of false alarm probability p_{fa} .

$$p_{as1} = \int_{v_T}^{+\infty} p(y/s) dy = \int_{v_T}^{+\infty} \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(y - \bar{y})^2}{2\sigma^2}\right] dy$$

In equations, $\sigma^2 = N + 2E_{ls}/N_0$; $\bar{y} = N + E_{ls}/N_0$; E_{ls}/N_0 is the signal to noise ratio at maximum side lobe locations.

$$p_{dm2} = \sum_{K=M}^N C_N^K p_{d1}^K (1 - p_{d1})^{(N-K)}$$

M is gate tolerance 2

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$$pas2 = pd1 \times pas21 + (1 - pd1) \times pas22$$

In equations, $pd1$ is the probability of exceeding gate tolerance 3.

$$p_{as21} = \sum_{K=M-1}^{N-1} C_{(N-1)}^K p^K (1 - p)^{(N-1-K)}$$

Here,
$$p = \int_{r_0}^{+\infty} r \exp\left[-\frac{1}{2}\left(r^2 + \frac{2E}{N_0}\right)\right] I_0\left(r \sqrt{2E/N_0}\right) dr$$
 At this time, $2E/N_0 = 0$

$$p_{as22} = \sum_{K=M}^{N-1} C_N^K p^K (1 - p)^{(N-K)}$$

In equations, M and r_0 are both precisely determined by the times main peaks are detected.

On computers, we are capable of graphing out change curves

associated with P_{dm1} , P_{dm2} , P_{as1} , and P_{as2} as functions of signal to noise ratios. P_{dm1} and P_{as1} are detection probabilities associated with main peaks and side lobes of determination system no.1 channels when signals are present. Their change curves as functions of signal to noise ratios are very difficult to graph out. Here, we only graphed out probability distribution functions associated with main peaks and side lobes when signals are present, as shown in Fig.7 and Fig.8. Fig.9 and Fig.10 are change curves for detection probabilities as functions of signal to noise ratios for main peaks and side lobes associated with determination system no.2 channels. That is also nothing else than change curves for P_{dm2} and P_{as2} as functions of signal to noise ratios. From these 4 curves, it is possible to see that fast acquisition system acquisition probabilities are only related to signal to noise ratios during determinations and are not related to signal wave forms.

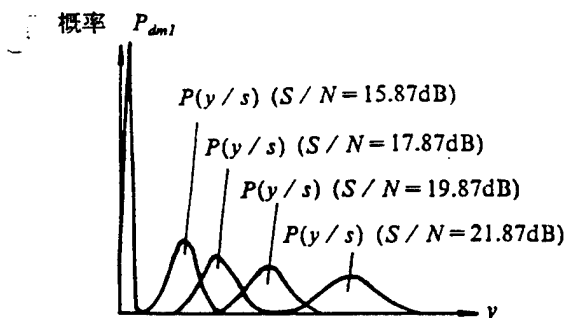


Fig.7 Probability Distribution Curves Associated with Main Peaks Plus Noise and Noise

Key: (1) Probability

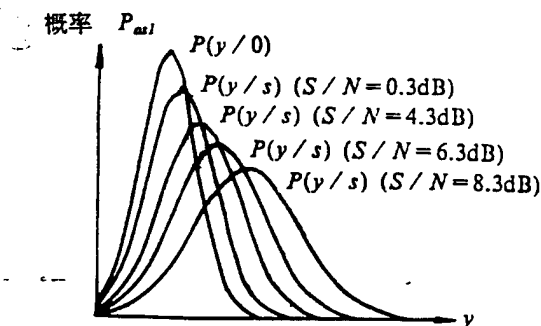


Fig.8 Probability Distribution Curves Associated with Side Lobes Plus Noise and Noise

Key: (1) Probability

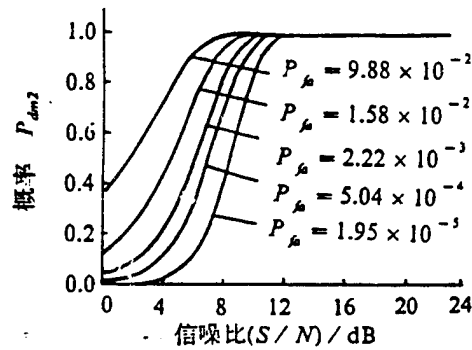


Fig.9 Change Curves Associated with P_{dm2} as a Function of Signal to Noise Ratios

Key: (1) Probability (2) Signal to Noise Ratio

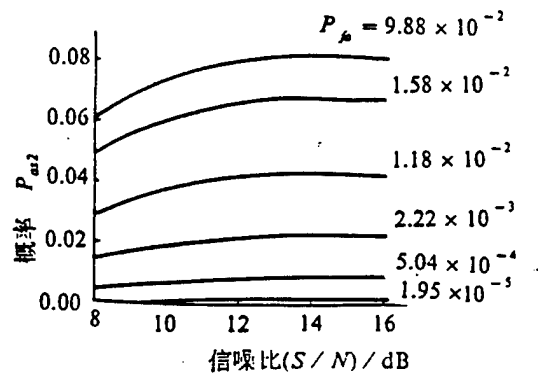


Fig.10 Change Curves Associated with P_{am2} as a Function of Signal to Noise Ratios

Key: (1) Probability (2) Signal to Noise Ratio

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Another important performance index associated with systems is false alarm probability. As far as false alarm probabilities here are concerned, there are two types of possibilities. One

type is false alarms created due to the detection of side lobes. The probabilities are nothing else than the pas obtained by calculations above. The other type is false alarms created by noise when there are no signals present. The probability is pra4. As a result, system false alarm probabilities are the sum of two parts.

$$pfa = pas + pfa4 = pas + pfa41 \times pfa42$$

pas has already been solved for above.

$$p_{fa1} = \int_{v_T}^{+\infty} p(y/0) dy = \int_{v_T}^{+\infty} \frac{1}{\sqrt{2\pi N}} \exp\left[-\frac{(y-N)^2}{2N}\right] dy$$

$$p_{fa2} = \sum_{K=M}^N C_N^K p_{fa2}^K (1 - p_{fa2})^{(N-K)}$$

Here, Pfa2 is the probability of exceeding gate tolerance 3 when no signals are present.

6 CONCLUSIONS

Starting out from the theory of detection determinations, this article has carried out a theoretical analysis with regard to fast acquisition systems. Detailed derivations were made of approximately optimum detection systems associated with synchronicity preamble signals. Finally, analyses were carried out with respect to approximately optimum detection system (those are also nothing else than fast acquisition system) detection capabilities, arriving at the fact that system performance is primarily determined by signal to noise ratios and is not related to signal wave forms. Fast acquisition systems as a whole went through test measurements. Test measurement results and the results of theoretical analysis were in line with each other.

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